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SOLUTIONS OF QUESTIONS

IN

AGNETISM AND ELECTRICITY

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IN

MAGNETISM AND ELECTRICITY

SET AT THE

Preliminary Scientific and First B.Sc. Pass Examinations of the University of London from 1860 to 1879.

TOGETHER WITH

DEFINITIONS, DIMENSIONS OF UNITS, MISCELLANEOUS EXAMPLES, ETC.

BY

F. W. LEVANDER, F.R.A.S.

ONE OF THE ASSISTANT MASTERS IN UNIVERSITY COLLEGE SCHOOL, LONDON.

LONDON
H. K. LEWIS, 136 GOWER STREET
1880

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Nov., 1880.

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UNIVERSITY OF LONDON:

CORRIGENDA.

Page 7, *line* 10, *dele* con-
,, 28, ,, 15, *dele* be
,, 43, ,, 8, *after* distance *insert* in such a way as to diminish repulsion at a given distance.
,, 43, ,, 17, *for* 3, 3; *read* 1, 1;
,, 43, *for lines* 21, 22, *read* $\frac{2 \times 4}{5^2} : \frac{1}{8^2} = 10 : x$,

$$\therefore x = \frac{25}{8} \times \frac{1}{64} \times 10 = \cdot 488...$$

$= \text{force of repulsion.}$

,, 51, *line* 7 from bottom, *for* oxygen *read* sulphuric acid
,, 56, ,, 2, *for* number of turns made by *read* length of
,, 62, ,, 3, *for* 4000 *read* 40000
,, 92, ,, 15, *after* which *insert* the current from

Electric Discharge.

Voltaic Electricity: the various Batteries.

Electromotive Force; Strength of Currents; Resistance; Ohm's Law.

Heating and Chemical effects of Electric Currents.

Action between Currents and Magnets; Electro-Magnetism.

Induced Currents; Magneto-electricity.

Thermo-electricity.

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The work done in urging a quantity of electricity Q through a circuit by an *electromotive force* E is EQ; also, the work done in urging a quantity Q through a conductor by means of a difference of *potential* E between its ends is EQ. Hence the dimensions of *electromotive force* and also the dimensions of *potential* are

$$E = \frac{W}{Q} = ML^2T^{-2}.\ M^{-\frac{1}{2}}L^{-\frac{1}{2}} = M^{\frac{1}{2}}L^{\frac{3}{2}}T^{-2}.$$

The *capacity* of a conductor is the quotient of quantity of electricity by potential. Its dimensions therefore are $M^{\frac{1}{2}}L^{\frac{1}{2}}.\ M^{-\frac{1}{2}}L^{-\frac{3}{2}}T^2 = L^{-1}T^2$.

The *resistance* of a conductor is the quotient of electromotive force by current, therefore

$$R = M^{\frac{1}{2}}L^{\frac{3}{2}}T^{-2}.\ M^{-\frac{1}{2}}L^{-\frac{1}{2}}T = LT^{-1}.$$

The *heat* generated in time T by the passage of a current C through a wire of resistance R (when no other work is done by the current in the wire) $= \dfrac{C^2RT}{J}$ gramme-degrees, where J [Joule's equivalent] $= 4{\cdot}2 \times 10^7$ ergs; and this is true whether C and R are expressed in electro-magnetic or electro-static units.

SOME OF THE MORE IMPORTANT LAWS.

1. The force of *magnetic attraction* or *repulsion* varies inversely as the square of the distance.

2. The force of *attraction* or *repulsion* between two *electrified* bodies, whose sizes are very small

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11. Two *parallel currents* in the same direction attract, but in the contrary direction repel, each other.

12. The *direction of the Ampèrian currents* at the south pole of a magnet is the same as that of the hands of a clock, and the contrary at the north pole.

SOLUTIONS OF THE QUESTIONS

IN

MAGNETISM AND ELECTRICITY.

A. MAGNETISM.

1. If you were provided with bar magnets how would you proceed to make another permanent magnet? Point out which will be the North pole of the magnet so made. State the phenomenon of Secondary Poles and point out how you could produce such poles. (1862).

If I had only two magnets I should place the North pole of the one and the South pole of the other, separated by a small piece of wood, on the middle of the bar to be magnetized. Then, raising the other ends of the magnets so as to make an angle of about 30° with the bar, I should draw them apart as far as the ends of the bar. Bringing them back in a semicircle to the centre of the bar, I should repeat the above process several times on both sides of the bar. The North pole will be that which was rubbed by the South pole of the inducing magnet. It would be better if the ends of the bar were placed on the poles of two

other magnets, these poles being in the same position as those of the inducing magnet.

By Secondary poles is meant that a magnet has more than two poles; they can be produced during the process of magnetization, by rubbing one end of the bar more frequently than the other, or better, by enclosing the bar in a helix, which has the direction of its turns changed several times, and then sending a current from a battery through it.

2. You are required to magnetize an iron bar permanently by the inductive action of the earth: how will you do it? Describe the polarity excited in the bar and state the difference between a bar of iron and one of steel when subjected to this process of magnetization. (1861).

The bar must be kept for some time in a position parallel to that of the dipping needle; this will make it temporarily magnetic. To render the effect more permanent, the bar should be sharply struck a few times with a hammer,—the torsion caused by the blow appearing to increase the coercive force. If a steel rod is held in the same position, it will be permanently magnetized without being struck. The lower end will be the marked pole.

3. State and explain what takes place when a magnet is broken in the middle. (1877).

Each part becomes a perfect magnet with opposite poles, showing that all the parts of the original

magnet are in the same peculiar polarised condition.

4. Explain how keepers serve to maintain the magnetism of permanent magnets. (1867).

Being acted upon by Induction a keeper becomes a temporary magnet, its north pole being at the south pole of the magnet: it therefore diminishes the magnetic field and tends to maintain the strength of the magnet.

5. When a number of equal magnets are combined to form a magnetic battery, explain why the power of the battery does not vary as the number of magnets combined. (1868).

A great deal of their power is lost by the enfeebling action of each magnet on its neighbour.

6. Describe exactly experiments by which a bar of steel and a similar bar of soft iron could be distinguished from each other in consequence of their different magnetic properties. (1871).

If a bar of steel is rubbed with a magnet it will retain its magnetism; whereas if a bar of soft iron is similarly treated, its magnetism will be only temporary. Or, if a wire is coiled round a steel bar, and a current sent through the wire, the bar will be permanently magnetized: if a bar of soft iron is similarly treated, it will retain its magnetism only so long as the current passes.

7. A piece of soft iron is placed at right angles to the magnetic meridian, and a freely suspended magnetic needle is caused to approach its two

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heated. What causes this heat? and from what source is the energy producing it originally derived? (1865).

When the disc is rotated induced magnetic currents are set up in it. These soon become so considerable as to retard the motion of the disc, but if the motion is persisted in, the induced magnetism is converted into heat, which is the equivalent of the work done in maintaining the motion.

13. How did Coulomb apply the method of oscillations to prove that the attractive or repulsive force of two magnetic poles on one another varies inversely as the squares of the distance? (1869, 1870).

A needle was first placed so as to be under the influence of the earth only, and the number of its oscillations in a certain time was counted. A bar magnet was then placed at a given distance in the magnetic meridian, and the oscillations of the needle again counted for the same time as before. The magnet was moved to a definite distance and the oscillations again counted, when the number was found to vary inversely as the squares of the distance.

14. What is meant by a magnetic field? (1878).

The neighbourhood of a magnet where are all the magnetic lines of force, or, in other words, the region within which a magnet exerts its force.

15. Define the magnetic moment of a magnet. Show how to measure the magnetic moment of a given magnet. (1878).

The magnetic moment, M, of a magnet is its directive force, and equals the product of the strength, P, of either of its poles and the distance, L, between them; *i.e.* $M = PL$.

To determine the magnetic moment of a magnet a very short needle is suspended so as to hang in the magnetic meridian over a zero line. The magnet, whose moment is to be measured, is placed upon this line, at right angles to it and in the plane of the needle, at such a distance that it produces a deflection of only a few degrees. Let θ = angle of deflection, d = distance between the centres of needle and magnet, and H = the horizontal component of the Earth's magnetism; then $M = H\, d^3 \tan\theta$.

B. TERRESTRIAL MAGNETISM.

16. State concisely all that you know regarding the magnetism of the earth, the position of its poles, and equator, the distribution of terrestrial magnetism and the variation which it has been proved to undergo. (1861).

The action of the earth on a magnet is simply directive, *i.e.*, it determines the position of the magnet relatively to the cardinal points, but causes no strain (or tendency to translation) on the point on which it is balanced. There are at present two places known in the northern hemisphere, one in North America, the other in Siberia, and

one in the southern, where the intensity is at a maximum; but at none does the dipping-needle stand *perfectly* vertical. The magnetic equator is an irregular line where there is no dip. Terrestrial magnetism varies in different places; the isoclinic lines (those passing through places where the dip is the same) are not parallel to the equator, nor are the isogonic lines (those passing through places where the declination, *i.e.*, variation from the astronomical north of the needle is the same) parallel to a meridian. The magnetic needle is subject to steady variations of long period, also annual and diurnal variations, as well as to irregular short-lived movements dependent on currents in the earth, which probably owe their origin in great measure to the heating power of the sun. The needle is also irregularly affected by the Aurora Borealis. (See also No. 17).

17. Describe the earth as a magnet. State what you know about its poles and its equator, and describe the behaviour of a compass-needle and of a dipping-needle, when carried from place to place on its surface. (1862, 1878).

Whatever may be the cause of the earth's magnetism, it may be regarded as to its effects in the light of a huge magnet, having in the northern hemisphere a pole which attracts the marked pole of a freely suspended magnet, and in the southern hemisphere one which attracts the other end of the same magnet. In this way the phe-

nomena exhibited by compass and dipping-needles may be readily explained. If we place a compass-needle at the centre of a bar-magnet, it will set at right angles to the latter, but on causing it to approach either pole, the contrary pole of the needle will be attracted. If a dipping-needle is placed at the centre of a bar-magnet, neither extremity will be affected, but as it is moved nearer either pole, its contrary pole will be gradually attracted, till it eventually assumes a vertical direction. These are precisely the same effects as are observed in the case of the earth. As a dipping-needle is carried from the line of no dip towards the magnetic pole, its dip becomes greater, till at the pole it would stand vertical; while a compass-needle would at the pole be at rest in any position. The magnetic poles do not coincide with the geographical; they are not diametrically opposite, nor do their positions remain unchanged. (See also No. 16).

18. If we call that the *marked* pole of a magnetic needle which points to the north, and if the earth be viewed as a large magnet, state generally the position of the *marked* pole. (1863).

In the southern hemisphere, as indicated by the dip of the unmarked pole of the dipping-needle.

19. Define the terms (as applied to the earth) magnetic meridian, magnetic equator, magnetic pole. How would a ship's compass behave in the neighbourhood of a magnetic pole? (1867).

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phenomena are connected with disturbance of terrestrial magnetism? (1874).

Those changes which require a long time to complete their cycle are called secular; such are the slow changes in declination and inclination. The term disturbance is applied to those temporary magnetic storms, by which the needle is irregularly affected, such as those caused by the Aurora, solar spots, and volcanic eruptions. (For the rest of the question, see No. 20).

22. Define the terms declination, dip, and diurnal variation, as applied to terrestrial magnetism.

A bar magnet which is capable of turning in any direction about a fixed point rests with its axis horizontal. How must the fixed point be situated with respect to the centre of gravity of the bar, if the magnet be (1) in London, (2) at the Magnetic Equator, (3) at Cape Town? (1879).

Diurnal variation is the term applied to a slight daily movement of the needle, differing in different places. It occurs both in declination and dip. As regards the former, soon after midnight the marked pole moves eastward, attains its maximum in about 6 or 7 hours, and, on its return journey, passes the mean magnetic meridian at about 10 a.m. In about 3 hours it reaches its extreme daily westerly range, passing the mean again at about 5 p.m. It is to this movement in declination that the term is usually applied. (For declination and dip, see No. 20).

The magnet would be subject to two forces, that of gravity and that due to terrestrial magnetism. At the magnetic equator the fixed point and the centre of gravity will coincide; at London the former must be nearer the marked pole, but at Cape Town nearer the unmarked, in order to preserve the horizontality of its axis.

23. Describe the most accurate method you are acquainted with for finding the magnetic meridian of a place experimentally, giving reasons for any precautions that are necessary. (1872).

A telescope is placed accurately in the astronomical meridian, at some little distance from a carefully suspended magnet, which carries at the end nearest the telescope a small lens, and at the other a cross of wires. The position of the telescope is noticed on a horizontal graduated circle; it is then turned so that the centre of the cross wires on the magnet may appear to coincide exactly with the centre of those fixed in the eye-piece of the telescope. The magnet is inverted, in order to counteract any errors of suspension, and the observation repeated. The magnet is then re-magnetized with its poles reversed, to counteract any irregular magnetization due to the quality of the steel, and the two observations repeated. The mean of the difference between the astronomical meridian and the positions of the telescope at the four observations will show the position of the magnetic meridian with respect to the astronomical.

24. What do we need besides magnetic declination and dip, to know completely the present state of the earth's magnetism at any point? (1865, 1866).

The earth's horizontal intensity at the given place.

25. If required to ascertain the relative magnetic intensity at two points of the earth's surface, how would you proceed to do it? (1860).

It is necessary to observe the oscillations which a horizontally suspended needle will make in one minute, when disturbed from its position of rest, and the dip at each place. From the former will be obtained the horizontal intensity, which divided by the cosine of the dip will give the total intensity for each place. The observations must be made with the same two needles.

26. Let the horizontal magnetic force be 3.8, and the vertical force 8·5; find the total magnetic force. (1877).

Total force $= \sqrt{(3{\cdot}8)^2 + (8{\cdot}5)^2} = \sqrt{14{\cdot}44 + 72{\cdot}25}$ $= \sqrt{86{\cdot}69} = 9{\cdot}31$.

27. In making an observation of dip, I first of all bring the circle into such a position that the needle points vertically up and down. Show that it is now swinging in a plane perpendicular to that of the magnetic meridian. (1873).

A needle when at right angles to the magnetic meridian is vertical, because in that position it is

acted on by the vertical component only, the horizontal component being ineffectual to move it.

28. What is meant by the dip of the magnetic needle? Describe a dip-circle, and show how, by means of such an instrument, the local magnetic meridian may be determined. (1876).

By the dip is meant that one end of a magnet, free to move in a vertical plane, points more or less downwards. In places north of the magnetic equator this will be the marked pole.

A dip-circle consists of a magnetized needle very carefully mounted on a horizontal axis and playing on a vertical graduated circle. The whole of this is capable of being rotated in a horizontal plane and its position noted on a horizontal circle. It is also provided with microscopes for reading the graduations, and with levelling screws. The instrument is so placed that the needle is vertical; it is then turned 90° on the horizontal circle, and the plane in which it now swings is that of the local magnetic meridian.

29. A magnetic needle is carried from London to another locality, and is there made to vibrate in a horizontal and also in a vertical plane. It is found that the former description of vibration is more rapid than that in London, while the latter is less so. What may be argued from these facts? (1863).

As we go northward or southward from the magnetic equator or line of least intensity, the

total intensity increases, but the horizontal diminishes. It therefore happens that a compass-needle will oscillate more slowly as we leave the magnetic equator, but the reverse is the case with the dipping-needle. Consequently in this case the needle has been carried to a place nearer the magnetic equator than London.

30. A declination needle makes 50 oscillations in one minute at a point on the earth's surface where the inclination is 60°, and 57 oscillations in a minute where the inclination is 45°. Compare the magnetic intensities at the two places. (1869).

Intensities at the two places

$$= \frac{50^2}{\cos 60^\circ} : \frac{57^2}{\cos 45} = \frac{50^2 \cos 45^\circ}{57^2 \cos 60^\circ}$$

$$\begin{array}{llll}
\log. \cos 45^\circ & = 9{\cdot}8494850 & \log. \cos 60^\circ & = 9{\cdot}6989700 \\
\log. 50^2 & = 3{\cdot}3979400 & \log. 57^2 & = 3{\cdot}5117498 \\
\hline
 & 13{\cdot}2474250 & & 13{\cdot}2107198 \\
 & 10 & & 10 \\
\hline
\end{array}$$

$$\log. 1767{\cdot}7315 = 3{\cdot}2474250 \quad \log. 1624{\cdot}5 = 3{\cdot}2107198$$

$\therefore$ intensities are as $1767{\cdot}7315 : 1624{\cdot}5 = 1{\cdot}0882 : 1$.

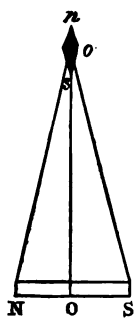
31. A magnetic needle, the magnetic moment of which remains constant, is suspended so as to move freely in a horizontal plane. When deflected from the magnetic meridian at three different places on the earth's surface, it is observed to oscillate 7·5, 8·3, 10·4 times respectively in one minute. Compare the intensities of the earth's

horizontal magnetic force at the three places. (1875).

$$(7{\cdot}5)^2 : (8{\cdot}3)^2 : (10{\cdot}4)^2 = 56{\cdot}25 : 68{\cdot}89 : 108{\cdot}16$$
$$= 1 : 1{\cdot}225 : 1{\cdot}918.$$

32. Explain how to determine the ratio of the magnetic moment of a magnet to the earth's horizontal magnetic force. (1878).

Place a bar magnet, NS, with its axis perpendicular to the magnetic meridian and notice the deflection that it causes on a short magnet, *ns*, freely suspended, so that when in the magnetic



meridian, the prolongation, *n*O, of its axis, bisects N*o*S. The deflection, θ, of *ns* will depend on the relative magnitudes of the horizontal component of the earth's magnetic force, H, and the field produced by NS. Let M = magnetic moment of the magnet and $r = o\mathrm{S} = o\mathrm{N}$, then $\frac{\mathrm{M}}{\mathrm{H}} = r^3 \tan \theta$.

C. STATIC ELECTRICITY.

33. How does it appear that the electricity developed by friction is of two kinds? Is that developed by rubbing a surface of glass always of one kind? Explain how the kind of electricity of any excited surface may be determined. (1860, 1861, 1869).

If glass, excited by having been rubbed with silk, is brought near a pith ball, the latter is attracted, and having touched the glass, immediately repelled. This shows that it has received a charge from the glass, and, as magnetic poles of the same kind repel each other, so two bodies charged with electricity of the same sort will repel each other. If the pith ball, while it is being repelled by the glass, is brought near a stick of sealing wax excited by having been rubbed with flannel, it will be attracted, showing that electricity of a different kind has been set up.

If glass is rubbed with silk it becomes positively electrified; but negatively, if rubbed with flannel or cat's skin.

The kind of electricity of any excited surface may be determined by the use of a gold leaf electroscope. This consists of two gold leaves, attached to the lower end of a metallic rod which passes through an opening in the upper part of a bell glass and terminates in a brass knob or plate.

The electrified body (or a portion of its charge) is brought near the knob. Electricity of the same sort is repelled into the leaves, making them diverge, while unlike electricity is attracted into the knob. The knob is touched with the finger; leaves, rod and knob will now have a charge of the opposite character to that of the influencing body. If the finger is removed and then the influencing body, the leaves, which had collapsed when the knob was touched, again diverge. Two uninsulated strips of metal, fixed to the inside of the bell jar, are inductively electrified by any charge on the gold leaves: the strips therefore attract the leaves and increase their divergence. If an excited glass rod is gradually brought near the knob and causes a diminution of divergence, the influencing body was electrified positively, but negatively if it causes an increase of divergence.

34. Describe experiments which show the existence of two different electrical conditions, and the propriety of the terms "positive" and "negative" as applied to them. (1861, 1868).

If an insulated conducting ball, A, is electrified by contact with rubbed wax, and another similar ball, B, electrified by contact with rubbed glass, and the two balls made to touch, they will, if equally charged, both assume the same neutral electrical condition; but if A had most electricity at first, the whole system will be electrified as if by rubbed wax, and *vice versa;* and, always, the

quantity of electricity on the two balls after contact is equal to the difference of charge on the two balls at first. The distinction between electricity due to rubbed glass and that due to rubbed wax, is therefore analogous to that between + and — algebraic quantities. (See also No. 33).

35. What proofs have we of the identity of the electricity developed by friction with that developed by the action of an acid and two metals? (1862, 1865).

By connecting one binding screw of a galvanometer with the prime conductor of an electrical machine in action and the other with the earth, the needle may be deflected. Also, water may be be decomposed by frictional, and a Leyden jar charged by voltaic, electricity.

36. Give a proof that statical electricity, though of high intensity, is very small in quantity. (1866).

The difficulty with which a galvanometer needle is deflected or water decomposed, both of which are easily done by voltaic electricity, the intensity of which is slight, will serve as a proof.

37. Two pith balls are suspended from a brass stand, the one by a silk, the other by a cotton thread. A piece of excited glass is found first to attract and then to repel the pith ball with the silk thread, while it continues to attract the pith ball with the cotton thread. Explain this. (1877).

The ball which is attached to the silk thread is

insulated, and is neutral. The glass being positively electrified attracts the ball and communicates some of its charge to it, thereby causing repulsion. The second ball is uninsulated and will continue to be attracted on account of the negative electricity induced on it.

38. A large insulated metallic cylinder, brought near the cap of a positively charged gold leaf electroscope, diminishes the divergence of the leaves. Show whether this effect affords *any* conclusive evidence as to the electrical condition of the cylinder, and if so, *what* it indicates. (1872).

The cylinder was charged with negative electricity; the divergence of the leaves is diminished because the positive electricity was attracted to the knob by the presence of the cylinder.

39. An insulated metallic cylinder, uncovered at the top, is connected by a wire with the cap of an electroscope. A charged brass sphere is slowly lowered, by means of a silk thread, into the cylinder, until it touches at the bottom; after which it is withdrawn. State and explain the behaviour of the electroscope during the course of the experiment. (1877).

If the sphere is charged with, say, positive electricity, as it is lowered into the cylinder, the leaves of the electroscope will diverge with positive electricity and will continue to do so until the sphere is about $\frac{2}{3}$ from the bottom of the cylinder, when they will become stationary and remain so

till and after contact. On removing the sphere it will be found to be perfectly discharged. This shows that the cylinder was charged by induction, and that the quantity of electricity thus developed on the outside of the cylinder must have been precisely equal to the charge on the sphere.

40. Describe and explain the construction and use of the electrophorus. (1868, 1874).

The electrophorus consists of a metal disc with an insulating handle, and a disc of ebonite cemented to a metal plate or dish. To use it, the ebonite is stroked with cat's skin, thereby decomposing the electricity of the disc, attracting the negative to the upper surface and repelling the positive to the lower and thence passing to the ground. The metal disc is then placed on the ebonite. Positive electricity is thereby attracted to the under surface of the metal, and negative repelled to the upper; this is got rid of by touching the upper surface with the finger, unless the ebonite is furnished with a metal pin passing from its upper surface to the uninsulated dish. (A resinous cake may be used instead of ebonite). Positive electricity then spreads over the whole surface of the metal disc, from which, when raised, a spark can be obtained. The ebonite will remain excited for a considerable time, but the process of placing the metal disc on the ebonite, touching it with the finger and raising it must be gone through before a spark will pass.

41. In the common electrical machine, state and explain the effect of insulating the rubber. (1862).

Very little electricity can be collected, since the negative generated on the rubber cannot be conveyed away. If the prime conductor is connected with the ground, negative electricity can be abundantly obtained from the rubber.

42. Explain the use of the prime conductor of an electrical machine. What differences are there in the electrical state of the conductor at different parts when the machine is at work? Explain how these differences can be determined. (1863).

The use of the prime conductor is to accumulate the electricity which has been produced by the friction of the glass against the rubber and collected by the points. The part of the conductor nearest the glass plate will be charged with negative electricity, the further part with positive, while the central portion will be neutral. These different conditions can be determined by means of a proof plane and gold leaf electroscope.

43. State the results which ensue when a conductor is made to touch an insulated electrified body, (1) when the former is insulated, (2) when it is uninsulated. (1860).

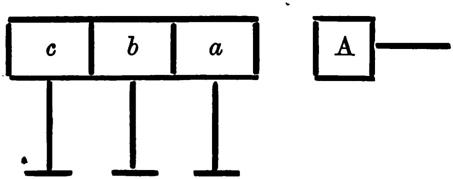
In the first case, the charge will be divided between it and the electrified body, in the ratio of their surfaces; the neutral electricity of the former being decomposed, that of the opposite sign is

attracted to the side nearest the electrified body, while electricity of the same sign is repelled to the further side. In the second case, the whole of the charge will pass to the ground.

44. Describe experiments showing that the free electricity in a charged body is entirely upon its surface. How is this phenomenon explained? (1867).

If a hollow sphere, in which there is a small circular opening, is charged with electricity, the proof plane will show that the outer surface is charged; but if carefully introduced into the hole, the edges of which should be well insulated, it will show that none resides on the inner surface. Again, if a conical muslin bag is set on an insulated ring, and so arranged that it may be turned inside out by means of a piece of silk fastened to its apex, the proof plane will show that the outer surface only is charged, whether the bag is inverted or not. This is due to the fact that each portion of a charge repels every other similar portion with a force inversely proportional to the square of the distance separating them.

45. A plate, A, is kept positively electrified, and three neutral metallic bodies, *a*, *b*, *c*, upon insulat-



ing feet, and in contact with each other, are made to approach A, but not so near as to receive a spark. When near A, first *c*, then *b*, then *a*, are successively removed by their feet; how will they be charged? (1864).

When in contact, *a* will be negatively, and *c* positively charged, *b* being neutral. When *c* is removed it will be still positively charged; the negative electricity on *a* will induce a charge of the opposite character on *b*, and when *b* and *a* are removed, the former will be positively charged and the latter negatively.

46. If a glass jar be electrified inside and be inverted on a table over pith balls, the balls begin to dance up and down; the motion presently ceases, and when on the point of ceasing may be renewed by simply passing the hands down the outside of the jar. Explain these phenomena. (1866).

The glass, being electrified, attracts the balls, each of which brings down some of the electricity from the glass. By passing the hands down the glass, the electricity on the outer surface is released, consequently the motion re-commences.

47. What is a disruptive discharge, and how does it differ from a charge by conduction? How is the light which attends such a discharge affected by the metals between which the discharge passes? (1860).

A disruptive discharge is one which causes a

disruption of the particles of air, accompanied by light and noise, whereas a discharge by conduction is invisible and inaudible. The different metals impart to the spark the characteristic colours which they exhibit when deflagrated. If wires are stretched on white paper and deflagrated, the following colours will be left on the paper :—

Brass wire leaves purple and brown.
Copper, green, yellow and brown.
Gold, purple and brown.
Iron, light brown.
Lead, brown and bluish grey.
Platinum, grey and light brown.
Silver, grey, brown and green.
Tin, yellow and grey.
Zinc, dark brown.

48. An insulated conducting cylinder is placed with one end near a positively charged ball; the point of the cylinder nearest to the ball is touched for an instant with the finger, and afterwards the ball is removed. State and explain the electrical effects which take place in the cylinder during the whole process. (1871).

Negative electricity is attracted to the end of the cylinder nearest the ball, and the positive repelled to the other. When touched by the finger, the positive electricity escapes, leaving the cylinder negatively charged.

49. Show how the inner coating of a Leyden

jar can be negatively charged by means of a common electrical machine with uninsulated rubbers. Also show whether the strongest charge that can be given to the inner coating of the jar in this way is of the same strength as the strongest charge that it can receive from the same machine, when it is charged in the usual way. (1871).

If the jar is held by the knob and the outer coating presented to the prime conductor of the machine, the inner coating will be negatively charged. As the capacity and potential will remain unaltered, the quantity will be the same in whichever way the jar is charged.

50. Explain the theory of the Leyden jar and show how to charge it. A quantity of electricity $= 5$ is conducted into the interior of a Leyden jar of surface $= 2$; and a quantity of electricity $= 6$ is conducted into the interior of a similar jar of surface $= 3$. Compare the heat developed by discharging each. (1875).

(1). A Leyden jar is merely a condenser, consisting of two conductors separated by a dielectric, and acting by induction. When the knob in connection with the inner coating of the jar is presented to the prime conductor of a machine in action, positive electricity accumulates on the inner surface of the inner coating; by induction a charge of the opposite character accumulates on the other side of the dielectric, *i.e.* on the inner surface of the outer coating. The outer surface

of the outer coating being in connection with the earth is at the same zero potential: if the two conductors were at the same potential, induction could not take place.

(2). $\frac{5^2}{2} : \frac{6^2}{3} = \frac{25}{2} : \frac{36}{3} = 25 : 24 = 1 : \cdot 96.$

51. How would you charge a Leyden jar by means of an electrophorus already excited? (1862).

When the metal disc is in contact with the ebonite, touch the former with the finger and then present it to the knob of the jar. Repeat the process until the jar is fully charged.

52. If a Leyden jar be charged in the ordinary way, state and explain the effect of touching the knob connected with the inner coating, when the jar is (1) insulated, (2) uninsulated. (1861).

If the jar is insulated a small spark only will pass, the positive and negative electricities will be unable to combine. If it is uninsulated, touching the knob will cause the jar to be discharged, connection between the two coatings being made through the body of the experimenter.

53. Two Leyden jars, one charged and one empty, are placed a little distance apart on a tray, and a wire is allowed to drop on the two knobs. Explain what would happen, supposing the tray made, (1) of glass, (2) of metal. (1867).

If the tray is of glass a very small quantity of electricity passes into the uncharged jar, but, if of

metal, the charge will be distributed between the two jars.

54. If a Leyden jar be discharged through a metal wire, state the several circumstances on which the heating of the wire depends. Suppose the wire to be a hollow pipe, what difference will this make? Give your reasons, or the general law applicable to the case. (1863).

The amount of heat developed is dependent on the quantity of electricity and the difference of potential; it is also directly proportional to the resistance of the connecting wire. If a pipe is used, there will be a difference due to a difference of metallic area, since the quantity varies, other things being similar, inversely as the fourth power of the diameter.

55. Describe the unit jar and explain its application to the measurement of the charge of a Leyden battery. (1870).

Lane's unit jar consists of a small Leyden jar, near which is a vertical metallic support connected with the outer coating. Through the upper part of this support slides a rod furnished at one end with a knob which can be placed at a measured distance from the knob of the jar. To measure the charge of a battery by means of this instrument, the former is insulated and its outer coating connected with the inner coating of the uninsulated unit jar. When the battery is charged, positive electricity passes into i

portionate quantity passing to the inner coating of the unit jar, and there producing a charge. When this has reached a certain limit, determined by the distance between the two knobs of the jar, a spark passes between them. This will happen as often as the same amount of electricity is added to the inner coating of the battery. The charge is measured by counting the sparks.

Harris' unit jar consists of a small insulated Leyden jar, one coating of which is connected with the uninsulated battery, the other with the prime conductor of the machine.

For small distances, the striking distance is directly proportional to the quantity of electricity and inversely proportional to the extent of coated surface.

56. Describe and explain the condenser. (1860, 1865).

This instrument consists of two insulated metallic plates, separated by, and capable of being placed at different distances from, a sheet of glass or other dielectric. One plate, A, is connected with the ground, the other, B, with the machine. Then, if the machine is worked till the limit of charge is reached, the surface of A facing B will be charged with negative electricity, held by attraction of the positive charge on B; conversely, the surface of B facing A will be charged with positive electricity, held by the negative on A, in addition to the charge which it would have, if A *and the* dielectric were absent.

57. The areas of the armatures of three condensers, exactly alike in all other respects, are as the numbers 3, 4, 5. Explain how you would charge them with equal quantities of electricity. (1876).

If the three condensers be charged by the same number of turns of the machine, they will all have the same tension, but the *quantity* of electricity on them will vary as the areas of their armatures, that is, it will be in the proportion $3:4:5$. Since the same quantity is required to be deposited on each area we must have the equations $3qx = 4qy = 5qz$, where q is the quantity of electricity given off at each turn of the machine and x, y, z, the number of turns required. These equations are satisfied by making $x = 20$, $y = 15$, $z = 12$. Consequently the three condensers will be equally charged from the same machine by giving it a number of turns in the proportion $20 : 15 : 12$.

58. Define electric induction, and show how, by its means, if we possess (to begin with) a small quantity of electricity, this may be increased indefinitely. (1876).

Induction is the name given to the influence exerted on neutral bodies by the proximity of an electrically excited one. The action of the electrophorus is due to induction, and the principle has been applied to various pieces of apparatus, such as Bennett's electrical doubler or multiplying condenser; Sir William Thomson's repl

isher for his quadrant electrometer; Holtz's and other machines. It is by such instruments, actuated originally by a small inducing charge, that a small quantity of electricity may be indefinitely increased.

The following is a description of Bennett's multiplying condenser.—On the top of, or otherwise connected with a gold leaf electroscope, is placed a flat metal plate, A; on the top of this is another similar plate, B, with its under surface varnished, and furnished with an insulating handle; this is surmounted by a third, C, having also its under surface varnished, and similarly fitted with a handle. To use it, first put B on A, touch B with the finger, and, before removing the finger, touch the plate A with the object, the electricity of which is to be multiplied. Remove the object and the finger. Take up B by its handle, place C on B and touch C with the finger. Place B on A, touch B with the finger, and apply the edge of C to A. Remove C, take the finger from B and raise B from A. Repeat the operation several times, until so much electricity is accumulated on A as to cause the gold leaves to diverge.

59. Explain the action of a point, whether in collecting or dispersing electricity. (1864, 1872).

A point may be considered as an elongated ellipsoid. The density of an electric charge on a conductor of this shape is found to be the greatest at the extremities. The accumulation of electri-

city on a point becomes so great with a large charge as to overcome the dielectric condition of the air, and will therefore disperse, or if it is near an electrified body collect, electricity. If a fine needle in connection with the ground is brought near a charged electrical conductor, it will be found that the point will cause all the electricity to be silently discharged from the conductor.

60. Explain the action of the electrical fly (Tourniquet Electrique). (1866).

The motion is due to the repulsion between the electricity given off at the points of the fly and that imparted to the adjacent air by conduction. The electricity, accumulating on the points, passes into the air, and thus giving a charge repels this electricity, while it is itself repelled.

61. Explain the action of lightning conductors and the reason for making them pointed. (1860).

When a storm cloud charged with, say, positive electricity, arises it acts inductively on the earth, repels the positive, and attracts the negative electricity, which accumulates on bodies placed on the surface of the ground and more abundantly on those which are at a greater height. The tension is greatest on the highest bodies, which are, therefore, more exposed to the electric discharge. If these are provided with points, the negative electricity flows into the atmosphere, neutralising the positive charge of the cloud. The lightning conductor, however, if the storm is violent, may be

inadequate for the purpose, and the lightning strikes; the conductor, on account of its greater conductivity, receives the charge, which under these circumstances does no damage. (See also No. 59).

62. Describe a method of determining the electric state of the air at a fixed point near to, but not in connection with, the surface of the earth. (1873).

A conductor having a flame or water-dropping arrangement at one end is connected with one pair of quadrants of a Thomson's Quadrant Electrometer. This pair of quadrants is thereby brought to the potential of the air at the spot to be tested; the other pair is connected with the earth, and the difference of potential is shown by the deflection of the needle. A gold leaf electroscope and metallic conductor may be substituted.

63. Two small insulated spheres, being both charged with positive electricity of the same intensity, are found to repel one another with a force of one grain. They are then both charged with positive electricity of double the former intensity; find the repulsive force which they will exert. (1864).

The force of repulsion, being equal to the product of the charges, will now be four grains.

64. Two insulated metallic spheres, being both charged with positive electricity, are found to repel one another with a force which, when the

distance is considerable, varies inver as the square of the distance. In what m d why will this law be modified whe es are brought near one another? (18

The mutual induction between th heres will disturb the distribution of ele over their surfaces, and consequently change dis-tribution at every change of distance.

65. Two equal small spheres, charged with quantities of electricity represented by the numbers 2 and 4, attract each other with a force represented by 10, when the distance between them $= 5$. If the spheres are allowed to touch and then separated by a distance $= 8$, what force will they exert upon each other? (1875).

Charges before contact $= 2, 4$,

,, after ,, $= 3, 3$;

the force of attraction being equal to the product of the charges divided by the square of the distance,

$$\therefore \frac{2 \times 4}{5^2} : \frac{3 \times 3}{8^2} = 10 : x$$

$$\therefore x = \frac{25}{8} \times \frac{9}{64} \times 10 = \frac{1125}{256} = 4{\cdot}39.$$

66. Two small insulated metal spheres are charged with quantities of electricity in the ratio 3 : 7 respectively, and, when placed at a distance from each other equal to several times their diameter, they are found to repel each other with a

certain force; they are then made to touch each other and afterwards separated to three times their former distance. Compare the force now exerted between them with that exerted before they were brought into contact. (1872).

Let a = distance at which they were first placed, then the force, as it varies inversely as the square of the distance, will be $\frac{3 \times 7}{a^2} = \frac{21}{a^2}$;

After contact the charges will be equally divided and the force will be $\frac{5 \times 5}{(3a)^2} = \frac{25}{9a^2}$,

$$\therefore \text{ forces vary as } \frac{21}{a^2} : \frac{25}{9a^2} = 189 : 25.$$

67. Describe the apparatus employed by Coulomb for investigating the law of force between two small spheres charged with electricity; and illustrate by means of an example the mode of using it. (1878).

Coulomb used the torsion balance, of which the following is a description. A glass cylinder placed on a wooden base has its upper part covered by a glass plate, in the centre of which is a hole and to this is fixed a long vertical glass tube. At the upper end of the tube is a graduated movable index and a fixed circle. Attached to the circle is a cocoon thread or wire, which passes down the glass tube into the cylinder and carries at its further extremity a fine rod of shellac, at one end of which is a small disc of leaf copper. This rod is counterpoised so as to be always in a horizontal

position. At the same level as the rod a graduated circle is engraved on the glass cylinder. Through an aperture in the cover of the cylinder is introduced a glass rod terminated at its lower extremity by a gilt pith ball. The ball is opposite the zero point, and before commencing the experiment the upper circle is made to read 0°: the zero points are so arranged that the pith ball and copper disc will now be in contact. The ball is then removed, electrified and replaced, when repulsion immediately takes place. In one experiment of Coulomb's the distance to which it was repelled was 36°, and in order to reduce it to 18° the index was moved through 126°, making a total torsion of the wire of $126° + 18° = 144°$. To reduce the distance to $8\frac{1}{2}°$ it was necessary to rotate the index 567°, giving a total torsion to the lower and upper parts of the wire of $567° + 8\frac{1}{2}° = 575\frac{1}{2}°$. Taking the angles of deviation as 36°, 18°, 9° and the angles of torsion as 36°, 144°, 576°, it is evident that while the first are as $1 : \frac{1}{2} : \frac{1}{4}$, the latter are as $1 : 4 : 16$, that is, that for a distance half as great, the repulsive force is four times as great, and for a distance one-fourth as great the force is sixteen times as great. The force, therefore, varies inversely as the square of the distance. The force of attraction is somewhat similarly determined.

68. Define precisely what is meant by the specific inductive capacity of a substance for electri-

city; and describe generally how this property may be determined. (1863, 1870, 1873).

Faraday discovered that all dielectrics do not possess in an equal degree the power of transmitting electricity, or, the same inductive capacity. The specific inductive capacity of a dielectric is the co-efficient by which the capacity of an air condenser must be multiplied in order to give the capacity of the same condenser when another dielectric is substituted for air. This is a constant quantity for each substance, and its accurate determination is of great importance.

The following is Faraday's method of comparing specific inductive capacities. The apparatus used consists of two identical instruments of the following description. A brass sphere, connected with a knob by a metal rod insulated with shellac, is enclosed in two brass hemispheres in such a manner that an intervening space is left to contain the dielectric, the larger and smaller spheres representing the two coatings of a Leyden jar. At the commencement of the experiment the space in both instruments contains air only. The hemispheres are connected with the ground, and the knob of one of them presented to the machine, thus charging the inner sphere. By touching the knob with a proof plane, the quantity of free electricity is measured by means of the torsion balance. The knobs of the two instruments are then connected and the torsion will be one half, showing

that the charge has become equally distributed over the two spheres, since they are precisely similar. The space in the second instrument is now filled with the substance to be examined and the torsion noticed as before. The charge of the air jar will now be reduced by contact with the other, and the torsion now shown compared with the loss sustained will be the specific inductive capacity of air compared with that of the other substance examined. For example, let there be air in one instrument and shellac in the other. The torsion of the free electricity on the sphere of the apparatus containing air was found by Faraday in a certain experiment to be 290°. When the two knobs were connected, the air jar showed a density of 114° and the other 113°. In the division the induction through the air lost 176°; while that through the lac gained only 113°. Therefore the specific inductive capacity of air to that of shellac = 113 : 176 = 1 : 1·55. (Faraday, *Exp. Researches*, 1187, etc.).

69. Define the terms potential, charge, capacity, specific inductive capacity and density, as employed in electrical science.

Describe the method employed by Faraday for determining the specific inductive capacity of shellac. (1879).

The potential at any point in the neighbourhood of, or within, an electrified body, is the quantity of work that would be required to bring

a unit of positive electricity from an infinite distance to that point, if the given distribution of electricity remain unaltered.

A conductor covered with latent electricity is said to be charged.

Capacity refers to the quantity of electricity required to charge a conductor to a certain potential.

Density is the term used to denote the quantity of electricity per square centimetre on a charged conductor. (For the rest of the question see No. 68).

D. DYNAMIC ELECTRICITY.

70. A plate of pure zinc and one of platinum are dipped into water acidulated with sulphuric acid: when the plates are caused to touch each other, what are the *visible* effects produced? State fully the chemical actions which take place at the same time. (1860).

The zinc is attacked by the acid, forming sulphate of zinc; bubbles of gas which can be proved to be hydrogen rise from the surface of the platinum which is not affected by the acid. The water is, in fact, decomposed.

71. If the two plates, instead of touching directly, be united by a wire, an electrical current will pass through the latter. By what means

would you prove the existence of such a current? In what direction will it pass through the wire? What do you mean by the direction of the current and how do you suppose the word "current" came to be thus applied? (1860).

If a wire conveying a current is allowed to pass over or under a freely suspended magnetic needle, the latter will be deflected. The direction of the current will be from the platinum to the zinc, and is always assumed to be from the place of high potential to that of low. As electricity flows from one conductor to another along a wire or other conducting substance, the word "current" came to be applied from the analogy of water flowing through a pipe.

72. Two clean half-crowns, with a piece of cloth soaked in dilute sulphuric acid between them, produce no effect on a galvanometer. A current is sent for a moment from silver to silver through the wet cloth, the coins afterwards behave like two different metals and produce a current. Explain this. (1861).

The acidulated water is decomposed, and on the surface of the half-crown which was momentarily connected with the negative pole of the battery, a film of hydrogen is liberated next the cloth, and on the corresponding surface of the other a film of oxygen. These act as the different metals in a Voltaic cell.

73. Give a distinct statement of Volta's theory

of contact and mention one or two of the weightier objections which have been urged against it. What part did Volta ascribe to the liquid conductor which he found it necessary to introduce into his pile? (1861).

According to the contact theory, if two heterogeneous snbstances are placed in contact, one of them always assumes the positive and the other the negative electrical condition. The generation of heat and the performance of mechanical work by the mere contact of two metals would be equivalent to a perpetual motion, and be opposed to the law which requires for the production of any power the equivalent consumption of some other power. Nevertheless, some very strong arguments have been brought forward in favour of this theory.*

Volta supposed that the wet cloth acted merely as a conductor as well as to prevent contact between the different pairs of metals.

74. Define the terms thermal conductivity, electrical conductivity (1876).

The greater or less facility which bodies possess for the transmission of (1) Heat, (2) Electricity.

75. Describe Daniell's battery: state the action which goes on in it and explain what are the advantages of its construction. (1862, 1864, 1870).

* Sir W. Thomson, "New Proof of Contact Electricity" in the *Proceedings of the Literary and Philosophical Society of Manchester*, Jan. 21, 1862.

An outer jar of copper is nearly filled with a saturated solution of sulphate of copper, crystals of which are placed on a shelf fixed inside the jar. In the copper vessel is placed a jar of unglazed earthenware containing a rod of zinc immersed in sulphuric acid diluted in the proportion of 1 part of acid to 10 parts of water. Binding screws are attached to the two metals. When the terminals are connected by a piece of metal the following action takes place. Hydrogen is liberated on the surface of the copper, but meeting the sulphate of copper the latter is reduced to sulphuric acid and metallic copper, which is deposited on the copper jar. The crystals on the shelf keep up the constancy of the solution of sulphate of copper, thus preventing the deposition of hydrogen on the copper and ensuring the constant action of the battery. Sulphate of zinc is formed in the porous jar by the combination of the oxide formed on the zinc with the sulphuric acid. To prevent what is known as local action the surface of the zinc is amalgamated. The zinc may be immersed in a solution of sulphate of zinc, in which case the oxide, combining with the oxygen, is reconverted into the sulphate.

The advantages of this form of cell are, that (1) no hydrogen is deposited, but, in its place, copper; (2) the solutions are easily kept constant; (3) no disagreeable fumes are evolved.

76. Describe Grove's nitric acid battery, and

state what occurs in its two cells when the current circulates. (1860, 1866).

In an outer jar of porcelain is an amalgamated plate of zinc immersed in diluted sulphuric acid; in an inner porous jar containing strong nitric acid is a plate of platinum. When in action, the zinc is converted into sulphate of zinc, the oxygen required being obtained from the water. The hydrogen is prevented from remaining free at the platinum pole by forming, with the nitric acid, water and nitrous acid. This is in part dissolved and in part appears as nitrous fumes.

77. Describe a Grove's constant battery and mention the advantages of this arrangement. (1866).

The advantages are that (1) having two liquids there is no polarization of the plates, the hydrogen which is generated being intercepted by the nitric acid and combining with it, thereby forming water and nitrous acid; (2) there is a very considerable difference of potential between the metals employed; (3) there is very little internal resistance. (For description see No. 76).

78. Describe Grove's gas battery. (1876).

Each element consists of a two-necked bottle, in each neck of which is placed a tube, open below, with a platinum wire hermetically sealed into its upper end. To the lower end of the wire is attached a plate of the same metal. The apparatus is filled with acidulated water, which is

then partly decomposed by a battery, consequently one tube of each element will be partly filled with oxygen and the other with hydrogen. The battery is after a short time removed, and, as soon as a metallic connection is made between the terminals of the platinum wires, a current is set up from the oxygen to the hydrogen, both gases gradually disappearing and water being again formed.

79. Explain what is meant by a *current* and by the *direction* of a current in electricity; also how to determine the direction of the current traversing any conductor. (1863).

When metals of different potentials are immersed in a liquid, a constant distribution and restoration of their electrical conditions takes place; this is called a current, and its direction is from a higher to a lower potential, in other words, the direction in which positive electricity flows. The direction of a current may be determined by placing the conductor over, and parallel to, an ordinary magnetic needle. If the marked pole turns to the West, the current is going from South to North and *vice versa.*

80. The internal resistance of a galvanic battery is equal to the resistance of 3 metres of a particular wire. Compare the quantities of heat produced, both inside and outside the battery, when the poles are connected by one metre of this wire with the quantities produced in the same time when they are connected by 37 metres of the same wire. (1871).

Let electromotive force $=1$, then, by Ohm's law, measuring the resistance in metres of wire $C=\frac{1}{3}$.

In the first case, $C=\frac{1}{3+1}=\frac{1}{4}$. The heat, H, disengaged being proportional to the resistance of the wire and the square of the strength of the current $=\frac{1}{16}$;

In the second case, $C'=\frac{1}{3+37}=\frac{1}{40}$, and $H'=\frac{1}{1600}$;

$$\therefore H : H' :: 100 : 1.$$

In the first case the heat is divided between cell and wire in the ratio of 100 : 1; in the second case in the ratio of 100 : 37.

81. What is meant by the strength of a current? Show from Ohm's law, how to obtain the current of greatest strength which can be produced from a battery of a given number of cells. (1869).

By strength of a current is understood the power that a current possesses to produce deflections of a magnetized needle, to cause chemical decomposition, or to raise the temperature of a given conductor. It is numerically equal to the quantity of electricity that passes in unit time.

Let C = strength of current, E = electromotive

force, R = internal resistance of each cell, r = external resistance and n = number of cells, then, by Ohm's law,

$$C = \frac{nE}{nR + r}$$
$$= \frac{E}{R + \frac{r}{n}}$$

This is a maximum if r be very small, which will be the case when the conducting wire is very thick.

82. Describe fully some means of measuring the strength of an electric current. (1860).

The strength of a current may be measured by means of a tangent galvanometer. This, in its simplest form, consists of a circular copper band or ring of thick wire, in the centre of which is placed a small magnetic needle. The angle to which this is deflected, when a current is sent through the copper wire, can be read on a horizontal circle by means of a light pointer of straw or aluminium attached to the needle. The strengths of currents are proportional to the tangents of the angles of deflection. The results will be simply relative, but the values may be obtained in electromagnetic measurement by the following expression :—

$$C = \frac{HK^2}{L} \tan \theta$$

where H is the horizontal component of the

earth's magnetism at the place of observation, K the radius of the ring, L the number of turns made by the galvanometer wire, and θ the angle of deflection. All measurements must be in centimetres.

Another (relative) mode of measuring current strength is by observing how many cubic centimetres of hydrogen are given off per minute in the electrolysis of water.

83. State the circumstances on which the strength of an electric current depends. (1860, 1861).

The strength, C, depends on the electromotive force, E, of the battery, the internal resistance, R, and the external resistance, r; by Ohm's law $C = \frac{E}{R + r}$

84. The internal resistance of one cell of Grove's battery is 20, while the resistance of the external wire is 2. If the intensity of the current in this arrangement be denoted by unity, what will be the intensity in an arrangement of 6 similar cells, the external resistance of the wire being still 2? (1866).

$$1 = \frac{E}{20 + 2}, \therefore E = 22,$$

$$\text{Intensity in 6 cells} = \frac{6\,E}{6 \times 20 + 2} = \frac{132}{122} = 1{\cdot}08.$$

85. Explain the terms "Induction Current,"

"Extra Current," and give the conditions of the induction of a current by a current. (1874).

Induction or induced current is the term applied to that current which is produced in a conductor by the influence of a neighbouring conductor or magnet.

When the wire through which a current is passing is long and has many convolutions, at the instant that a current begins and ends, extra currents are induced by the action of the several parts of its circuit upon each other, that at the beginning of the current being inverse in direction, and that at the end direct.

When a current begins to flow, or receives a sudden increase, or approaches, or is approached by, a neighbouring conductor, an inverse current is induced in the latter; when the primary current ceases, or is suddenly diminished, or moved away from a neighbouring conductor, a direct current is induced in the latter.

86. Describe some one means of exciting an induced current of electricity. (1860).

An induced current may be excited by having two lengths of insulated wire coiled on the same cylinder. These may be wound side by side, or one coil may be completed before the other is commenced: in either case there is no connexion whatever between the two wires. On sending a current from a battery through the one coil, the deflection of the needle of a galvanometer will

show the presence of an induced current in the other. The same effect will be produced by passing a permanent magnet through the coil.

87. Having a permanent magnet and a coil of copper wire, state a method by which you could make an electric current circulate through the wire, and find its direction. (1866, 1878).

By suddenly placing one pole of the magnet within the coil, an induced current will be set up in the latter, though only of momentary duration; on its withdrawal, a current in the opposite direction is temporarily set up. By attaching the coil to a galvanometer, the direction of the first current will be found to be contrary to that which circulates round the magnet according to Ampère's theory.

88. A long insulated copper wire is coiled upon a short hollow wooden cylinder. State what electrical effects would be produced in the wire by passing a long straight magnet through the cylinder, putting it in at one end and drawing it out at the other. (1871, 1878).

When the north pole of the magnet is introduced, a temporary induced current is immediately set up in the coil, in a direction opposite to that in which the current circulates round the north pole of the magnet, *i.e.*, in the same direction as the hands of a watch. The galvanometer needle returns to zero, and, when the south pole of the magnet is being drawn out, will indicate the

presence of another temporary induced current in the opposite direction.

89. What is meant by electrical resistance? What circumstances in regard to a wire must be known before its resistance can be estimated? What is the relation between the resistance and these circumstances? (1867, 1878).

By resistance we mean that if two bodies at different potentials are united, the current produced takes a sensible time in passing from one to the other.

In order to determine the resistance of a wire, it is necessary to know its specific resistance, as well as its length and sectional area or weight per unit of length.

The resistance of any wire is expressed by the formula $\frac{rl}{s}$, where $r =$ its specific resistance, $l =$ its length, and $s =$ its sectional area or weight per unit of length.

90. Explain a method of comparing the electrical resistances of two wires. (1873, 1874).

The two wires are placed in turn in a circuit containing a tangent galvanometer. A comparison of the deflection of the needle caused by the introduction of each wire into the circuit will show their relative resistances, if they are of the same length and diameter, but of different conductivity, or *vice versa*. Or a rheostat may be used. The whole of the rheostat wire is wound on the wooden

cylinder, and the deflection of the needle of a galvanometer noted. One of the wires is now introduced, and the deflection again noted; this will of course be less than before. As much of the rheostat wire is unwound as will make the deflection the same as at first. The same process is repeated with the second wire. The ratio of the resistances of the two wires will be proportional to the lengths of wire unwound in each experiment. Or a set of resistance coils and a bridge may be used.

91. Compare the resistances of two copper wires, one of them 8 feet long and weighing $\frac{1}{4}$ of an ounce, the other 14 feet long and weighing $\frac{6}{7}$ of an ounce. (1873).

Resistance in a wire is directly proportional to the length and inversely proportional to the weight per unit of length :—

$$\text{weight of } a \text{ per foot} = \tfrac{1}{4} \times \tfrac{1}{8} = \tfrac{1}{32} \text{ ounce,}$$

$$\text{,, ,, } b \text{ ,, ,,} = \tfrac{6}{7} \times \tfrac{1}{14} = \tfrac{3}{49} \text{ ,,}$$

$$\therefore \text{resistance of } a : \text{that of } b = \tfrac{3}{49} : \tfrac{1}{32} \text{ per foot,}$$

$$\therefore \text{total resistance of } a : \text{that of } b = \tfrac{3}{49} \times 8 : \tfrac{1}{32} \times 14$$

$$= \tfrac{24}{49} : \tfrac{7}{16}$$

$$= 384 : 343$$

$$= 1 \cdot 1195 : 1$$

92. Using a single cell, I determine accurately the resistance of a fine platinum wire. I next apply a battery of 30 cells and make the same determination also accurately. Nevertheless the

two results do not agree. State the nature of the difference and assign its cause. (1873).

If a short coil galvanometer of small resistance is used, the addition of the 30 cells will cause the needle to be deflected *slightly* more than with the single cell; but if a galvanometer of great resistance is used, the deflection will be much greater. These differences are due to the extra resistance of the cells, and will consequently cause the resistance of the added wire to appear to be different from the result obtained with a single cell.

93. The resistance of a piece of platinum wire l metres long and $\left(\frac{1}{m}\right)^{\text{th}}$ of a millimetre in diameter is found to be R. What will be the resistance of a bar of the same material one centimetre long and one square centimetre in section? (1877).

Resistance $= \frac{rl}{s}$, where $r =$ specific resistance of platinum, $l =$ the length of the wire, and $s =$ its sectional area.

In the first case $l = 1000l$ millimetres,

$$s = \frac{\pi}{4m^2} \text{ square millimetres,}$$

$$\therefore \text{R} = 1000\, rl \div \frac{\pi}{4m^2} = \frac{4000\, m^2 rl}{\pi}$$

In the second case let $\text{R}' = \frac{rl'}{s'}$, where $l' = 10$ millimetres, and $s' = 100$ square millimetres,

$$\therefore R' = 10r \div 100 = \frac{r}{10};$$

$$\text{Hence } R' : R = \frac{r}{10} : \frac{4000\, m^2rl}{\pi}$$

$$= \pi : 4000\, m^2l$$

$$\therefore R' = \frac{\pi}{40000\, m^2l} R$$

94. The poles of a thermo-electric pile are connected by two copper wires, one 10 feet long and $\frac{1}{20}$ of an inch in diameter, the other 15 feet long and $\frac{1}{10}$ of an inch in diameter. What is the intensity of the current in each of these wires, that which would pass in the thinner wire, if the other wire were removed, being taken as unity? (1867).

Let a and b represent the two wires, then

$$\text{resistance in } a : \text{resistance in } b = \frac{10}{(\frac{1}{20})^2} : \frac{15}{(\frac{1}{10})^2}$$

$$= 10 \times 400 : 15 \times 100$$

$$= 2 \times 4 : 3 \times 1$$

$$= 8 : 3$$

and intensity being inversely proportional to resistance, we have

$$\text{intensity in } a : \text{intensity in } b = 3 : 8.$$

$$= 1 : 2\tfrac{2}{3}.$$

95. A circuit is formed containing galvanometer, battery and connecting wires, the total resistance of the circuit being 4·85 Ohms. The galvanometer shows a deflection of $48\frac{1}{2}°$. When a piece of platinum wire is introduced into the circuit, the deflection falls to 29°. From these

a determine the resistance of the platinum :e, given tan $48\frac{1}{2}^\circ = 1{\cdot}121$ and tan $29^\circ = 0{\cdot}485$. 878).

$485 : 1{\cdot}121 = 4{\cdot}85$: total resistance in Ohms,
$1 : 1{\cdot}121 = 1 : 11{\cdot}21$
$\therefore$ resistance of wire introduced $= 11{\cdot}21 - 4{\cdot}85$
$= 6{\cdot}36$ Ohms.

96. Explain how to compare the electrical resistances of two wires by means of Wheatstone's bridge. (1878).

Place in two of the gaps resistances, R_1 and R_2, that bear a convenient ratio to each other, a third, R_3, in the third gap, and in the remaining gap one of the wires whose resistance (x) is to be determined. When the connections are made and the galvanometer needle remains steady, it will be found that $R_1 : R_2 = R_3 : x$. The process is then repeated with the second wire. It will be most convenient to use Kirchhoff's modified form of bridge.

If merely relative resistance is required, equal resistances are placed in one pair of gaps, and the two wires in the other pair. The relative resistances will be shown by the relative lengths of the two portions of the fixed resistance, when the galvanometer needle remains steady.

97. Given a cell of Grove's battery, a galvanometer and a set of resistance coils, describe how you would determine the internal resistance of the cell. (1876).

The problem may be solved in several ways: the following is one of the best methods. The resistance of the galvanometer must be very slight or accurately known. Connect the galvanometer and cell, and notice the deflection. Add one of the resistances from the set and again note the deflection. The two currents thus measured will be inversely as the resistances, since the electromotive force remains unchanged. If G = the resistance of the galvanometer, R = the resistance introduced, C_1 and C_2 the strengths of currents, then we can obtain x, the resistance of the cell from the following:—

$$C_1 : C_2 = x + G + R : x + G.$$

98. Explain how the distance between the plates of a galvanic battery affects the temperature of a given wire, which connects the two poles of a battery. (1864).

The total amount of heat generated equals that generated in the cell and in the conducting wire. If the distance between the plates is increased, the internal resistance will be greater and the strength of the current diminished; consequently the temperature of the wire will be less.

99. If you had given six similar cells, say of Smee's battery, charged but not connected, in what different ways might you practically proceed to connect them? and under what circumstances would one or other mode of connexion be preferable? (1865).

They might be connected so as to form a series of six cells; or of three, each consisting of two cells; or of two, each consisting of three cells; or they might be connected so as to form a single large cell. The first mode is preferable for showing attraction and repulsion of currents, electrolysis, etc.; the last for the evolution of heat. In all cases, the best effects are obtained when the internal resistance equals the external.

100. What is meant by an electromotive series? Given a number of different metals, how would you determine their relative places in the electromotive series for a particular liquid? (1875).

In reference to their electrical behaviour, the metals have been arranged in what is called electromotive series, in which the most electro-positive are placed at the one end, and the most electro-negative at the other. When any two of these are placed in dilute acid, the current in the connecting wire proceeds from the one lower in the list to the one higher. For example, zinc, copper, silver, gold, platinum, graphite. The relative places of different metals for a particular liquid may be determined by fitting them up in cells under the same conditions and observing the effects on a tangent galvanometer.

101. Define the term electromotive force. (1868, 1872, 1879).

The force to which is due the property of producing a difference of potential.

102. The current from a battery of 10 equal elements passes through a Voltameter, and 50 cubic centimetres of hydrogen are produced in one minute. Fifty metres of wire are now introduced in addition into the circuit, and the volume of hydrogen now evolved in the Voltameter per minute is 30 cubic centimetres. If the resistance of 2·5 metres of the introduced wire be the unit of resistance and the unit of current be that which disengages one cubic centimetre of hydrogen per minute, what is the electromotive force of one element of this battery? (1868)

$$(1)\ 50 = \frac{E}{R}, \qquad (2)\ 30 = \frac{E}{R + \frac{50}{2\cdot 5}} = \frac{E}{R + 20}$$

$$\therefore E = 50\,R$$
$$\text{and } E = 30\,R + 600$$
$$\text{Hence } 0 = 20\,R - 600$$
$$\therefore R = \frac{600}{20} = 30$$

and, from (1), $E = 50\,R = 1500$.

Hence, for one element, $E = \frac{1500}{10} = 150$.

103. An electric current traverses a wire. State the relations between

(1) the electromotive force, the current and the resistance;

(2) the electromotive force, the current and the heat generated;

(3) the current, the resistance and the heat generated.

Show that the third relation follows from the first and second. (1879).

A. (1) $E = CR$.
(2) $H = EC$ per unit of time.
(3) $H = C^2R$ per unit of time.

B. From (1), $E = CR$

$$,, \quad (2), \; E = \frac{H}{C}$$

$$\therefore \frac{H}{C} = CR$$

$$\text{or } H = C^2R$$

104. The poles of a Grove's cell being connected with the terminals of a tangent galvanometer, a current of strength 24 was produced: the resistance of the circuit was then increased by one unit (all else remaining as before) and the strength of the current was now found to be 11. Calculate from these data the electromotive force of the cell. (1872).

$$(1)\; 24 = \frac{E}{R}, \qquad (2)\; 11 = \frac{E}{R + 1}$$

$$\therefore E = 24\,R$$

$$\text{and } E = 11\,R + 11$$

$$\text{Hence } 0 = 13\,R - 11$$

$$\therefore R = \frac{11}{13}$$

$$\therefore \text{from (1)}, \; E = \frac{264}{13} = 20\frac{4}{13}.$$

105. How may the electromotive force of Grove's

gas battery be compared with that of any other form of battery? (1876).

A tangent galvanometer and a rheostat are placed in the circuit so that the current, C, causes a certain deflection of the needle. A greater length, L, of the rheostat wire is then introduced, so that a diminished current, C′, is obtained. The cell with which the comparison is to be made is then substituted for the Grove's cell, and, by means of the rheostat, the current is first made equal to C, then, by introducing L′ length of rheostat wire, equal to C′. Let E, E′, be the electromotive forces, R, R′, their resistances when the currents are of strengths C, C′, and L, L′ the lengths of rheostat wire introduced, then

$$\text{for the trial cell } C = \frac{E}{R}, \quad (1)$$

$$C' = \frac{E}{R + L}, \quad (2)$$

$$\text{for the comparison cell } C = \frac{E'}{R'}, \quad (3)$$

$$C' = \frac{E'}{R' + L'} \quad (4)$$

From (1) and (3),

$$ER' = E'R$$

From (2) and (4),

$$ER' + EL' = E'R + E'L$$

$$\therefore EL' = E'L$$

$$\therefore E : E' = L : L'$$

Hence the electromotive force of the cells com-

pared are directly as the lengths of wire interposed.

106. Enumerate, completely, the laws of chemical action of the Voltaic current. (1877).

(1). In order to effect electrolysis, the electrolyte must be a conductor.

(2). The energy of the electrolytic action of the current is the same in all its parts.

(3). The same quantity of electricity—that is, the same electric current—decomposes chemically equivalent quantities of all the bodies which it traverses; from which it follows that the weights of elements separated in these electrolytes are to one another as their chemical equivalents: therefore

(4). The quantity of a body decomposed in a given time is proportional to the strength of the current. (*Faraday's* Laws).

107. A current of electricity is passed through a Voltameter containing acidulated water. How would you show that the quantity of water decomposed in a given time is directly proportional to the strength of the current? (1876).

By introducing into the circuit a rheostat, so that the strength of the current may be increased or diminished at pleasure, it will be found that the quantity of hydrogen liberated by electrolysis is directly proportional to the strength of the current. As oxygen is slightly soluble in water, the quantity of hydrogen only should be noted, if exact *results are desired.*

108. If the current of a battery of 10 Grove's cells, connected in series, is sent simultaneously through two Voltameters, containing respectively a solution of cupric sulphate and a solution of silver nitrate, and placed one after another in the circuit, show how much copper and how much silver will be deposited, while 3·25 grammes of zinc are dissolved in the entire battery. Also show how much copper and silver would be deposited, if the battery were arranged in two parallel series of 5 cells, instead of in a single series of 10 cells. ($Zn = 65{\cdot}0$; $Cu = 63{\cdot}4$; $Ag = 108$). (1872).

From Faraday's third law of electrolysis, in the first case ·325 gramme of zinc will be dissolved per cell, therefore

65 : 63·4 : : ·325 : ·317 gramme of copper
and 65 : 108 : : ·325 : ·54 ,, silver.

In the second case, the same quantity of zinc per cell being dissolved, each series would deposit the same quantity of copper and silver, the total of which would therefore be ·634 and 1·08 grammes respectively.

109. Describe an induction coil. Explain how the two induction currents are produced, and what is meant by the *direction* of the secondary current. (1877).

There are five essential parts in an induction coil,—the core, the primary wire, the secondary wire, the condenser and the break. The core consists of a great number of pieces of thin soft

iron wire, made into a firm bundle and carefully insulated. Round the core is wound the primary wire, consisting of a comparatively short length of thick insulated copper wire: each layer is well insulated by means of paraffined paper and the whole enclosed in an ebonite tube, which should be thicker at the ends than in the centre. On this is wound the secondary coil, consisting of a great length of very thin insulated wire, with its turns parallel to those of the primary. In very small coils the secondary is wound continuously from end to end, but in more powerful instruments it is built up in sections, each separated from its neighbour by an ebonite disc. The tension at the ends is greater than elsewhere and it is for this reason that the insulating tube is thicker at those parts. A greater length of wire is wound in the central compartments than in those nearer the ends, since the inductive power in an electro-magnet is greatest at the centre and becomes feeble at the ends. Not only is every layer well insulated, but the whole when complete is thoroughly soaked in paraffin, so that no air spaces may be left. The size of the wires used for the primary and secondary will depend on the size of the coil, the battery power intended to be used, and the character of spark desired. For the primary the diameter of the wire will range from 0·04 to 0·1 of an inch, and for the secondary from 0·008 to 0·004 of an inch; that of the wire composing the core, from 0·05 to

0·03 of an inch. The condenser is composed of several pieces of tinfoil and an insulating material, usually paraffined paper, placed alternately. Each piece of the insulator is larger than the metal and so arranged that one edge of every alternate piece of tinfoil may project on either side: these protruding edges are then severally soldered and a stout wire affixed. There are two forms of break, one known as the vibrating or hammer and anvil, the other the mercury, which is used only with very powerful coils; the object of either is to make and break very quickly and suddenly the current sent into the primary coil. The vibrating break is usually made so as to utilise the temporary magnetism of the core. It consists of a strong spring fastened vertically to the base of the instrument, carrying at its upper end a piece of soft iron, and at about its centre a platinum plate; a screw tipped with platinum passes through a metallic support at such a height that it may touch the plate. In the mercury break, a wire is made, either automatically, or by clock-work, or by the hand, to alternately make and break contact with the surface of mercury. One of the wires attached to the condenser is soldered to the lower end of the spring of the vibrating break and to one end of the primary wire, the other to the pillar carrying the screw and to one of the terminals for connection with the battery. The other end of the primary is

connected with the second terminal. An arrangement is also made for cutting off, or reversing the direction of, the battery current. When in action the current from the battery passes into the primary and by induction a current is set up in the secondary. But the primary current makes the core an electro-magnet which in consequence attracts the soft iron armature of the spring, causing the platinum plate to leave the screw against which it pressed. This, it will be seen, breaks the continuity of the current, another induced current is set up and at the same time the core loses its magnetism, the spring returns to its original position, and the primary circuit is again complete, to be again broken and renewed so long as the battery continues in action. The extra current set up at each renewal of the primary current is in the contrary direction, but at break of contact in the same direction as the vanishing primary. When the primary current is complete and re-acts on the secondary, a great enfeeblement of the latter is the consequence, but when the primary is interrupted, the re-action not existing, there is no enfeeblement of the secondary, the full power of which is developed, consequently we obtain discharges in a single direction only instead of discharges alternating in direction.

110. A current crosses a magnetic needle at right angles; two effects are possible—what are they? The same current is caused to run parallel

to the needle, assume a direction and describe its effect. (1861, 1864).

If the current goes over, and at right angles to the needle, from east to west, the north pole goes to the south.

If the current goes under, and at right angles to the needle, from east to west, the intensity is increased.

If the current goes over and at right angles to the needle, from west to east, the intensity is increased.

If the current goes under, and at right angles to the needle, from west to east, the north pole goes to the south.

Also, if the current goes over, and parallel to the needle, from north to south, the north pole goes to the east.

If the current goes under, and parallel to the needle, from north to south, the north pole goes to the west.

If the current goes under, and parallel to the needle, from south to north, the north pole goes to the east.

If the current goes over, and parallel to the needle, from south to north, the north pole goes to the west.

111. Describe the construction and explain the principles of the Astatic galvanometer. (1860, 1867, 1871, 1874).

Two magnetic needles, of nearly equal inten-

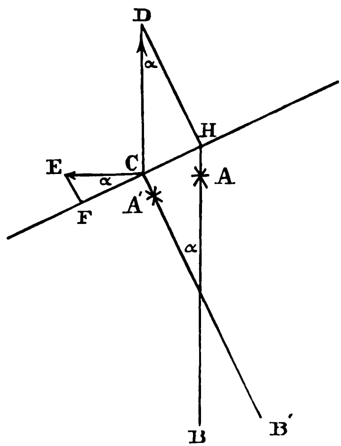
sity, rigidly attached with their poles reversed, are suspended by a silk fibre in such a manner that one is within, and the other above, a coil of insulated wire, or each may be within a coil. The upper needle, or a pointer attached to it, indicates on a graduated circle the deflections caused by the current. It is evident (see No. 110) that both needles will, by the action of the current, tend to turn in the same direction. As the poles are reversed the force of the horizontal component is much reduced, and consequently a given current will produce a greater deflection with an astatic than with a single needle galvanometer.

112. Describe the reflecting galvanometer. (1873).

The needle or astatic system is very light and has attached to it a small mirror. A screen is placed at some little distance from the instrument and a scale marked on it, graduated from zero in the centre. Below the zero mark is a small hole through which the light of a lamp placed behind the screen falls on the mirror, from which it is reflected to the screen, and there the deflections of the needle are noted by observing the motions of the spot of light. The angle formed by the reflected ray will be twice the angle through which the magnet and mirror are deflected. By means of a magnet, the distance of which from the coil is adjustable within certain limits, the directive action of the earth on the needle may be increased or diminished.

113. Show that the strength of a current passing round a tangent galvanometer is proportional to the tangent of the angle of deflection. (1878).

Let AB be the direction of a needle at rest in the magnetic meridian and A′B′ its position after having been deflected through an angle α by the action of a current, also in the magnetic meridian. It is only necessary to consider the forces acting on C; these are (1) the directive force of the earth in the direction CD, and (2) the repellent force of the current in the direction CE, and,



since C is at rest, the resolved parts of these forces at right angles to CB′ will be equal and opposite. Let these be represented by CF, CH, and at right

angles to FH let FE, HD be drawn; CD and CE will then represent respectively the force due to the earth's magnetism and that due to the current.

$$\begin{aligned} \angle \mathrm{CDH} &= \angle \mathrm{ECF} = \alpha \\ \mathrm{CF} &= \mathrm{CE} \cos \alpha \\ \mathrm{CH} &= \mathrm{CD} \sin \alpha \\ \text{and } \mathrm{CF} &= \mathrm{CH} \\ \therefore \mathrm{CE} \cos \alpha &= \mathrm{CD} \sin \alpha \\ \text{or } \mathrm{CE} &= \mathrm{CD} \tan \alpha. \end{aligned}$$

114. Describe some simple form of Thomson's quadrant electrometer. (1874). Explain the principle of the quadrant electrometer, including the suspension of the needle. (1879).

In the simplest form a broad flat aluminium needle is suspended by a platinum wire having a mirror attached to it from the inner coating of an inverted Leyden jar. The needle hangs over four quadrant-shaped plates of metal, each insulated from the earth and its neighbours. The opposite pairs of quadrants are united by means of wires, and terminals are attached to them.

In the more complicated form of the instrument the Leyden jar is not inverted, the needle hangs inside a shallow cylindrical brass box cut into four quadrants, and is suspended by two silk fibres, the other ends of which are wound upon two pins, which may be turned in their sockets by a key so as to equalize the tensions of the fibres and make the needle hang midway between the upper

and under surfaces of the quadrants. To the needle is attached, by a wire, a piece of platinum dipping below the surface of the sulphuric acid which forms the inner coating of the Leyden jar. There is also a replenisher (a small inductive apparatus) by which the charge of the jar can be increased or diminished at will and a gauge by which the constancy of the charge can be measured. (For a complete description see Sir W. Thomson's *Papers on Electrostatics*, pp. 262—281).

If one pair of quadrants has a higher potential than the other, the needle will experience a force urging it from the place of high potential to that of low potential.

115. Explain how Thomson's quadrant electrometer is used to measure the electromotive force of a galvanic battery. (1874).

In order to determine the electromotive force of a battery or the difference of potential between its plates, the latter are connected with the terminals of the galvanometer, and the deflections of the needle as indicated by the spot of light on the screen noted.

116. A current is sent through a wire which surrounds a bar of soft iron; what occurs? Assuming a direction for the current, show by means of a sketch the polarity excited in the bar. (1860).

The soft iron will become temporarily magnetic, and that end of the bar, round which the current

circulates in the same direction as the hands of a watch, will be the south pole of the magnet.

117. Describe some experiments which show that the wires conducting electric currents attract each other when the currents are moving in the same direction, and repel each other when they are moving in opposite directions. What bearing have these effects on Ampère's theory of magnetism? (1869).

To show the attraction and repulsion exercised by currents on currents, it is necessary to be provided with an Ampère's stand, or some modification of it. The following is a description of a modified form of the instrument. In the centre of a base board, provided with levelling screws, is a circular mercury trough, divided by an insulator into two concentric channels, each of which is connected with one of two binding screws. From the centre rises a pillar terminating in a cup and supporting on a point a stout wire rectangle whose ends dip into the channels of the mercury trough. In connection with the binding screws there rise from the base of the instrument, and diametrically opposite each other, two split metal tubes into which can be fitted the ends of a larger rectangle. When currents are sent in the same direction through the two rectangles they will attract each other, but if sent in opposite directions repulsion will ensue.

Ampère's theory of magnetism is that currents

circulate round magnets, and if two of these currents circulate in the same direction they are attracted, and *vice versa*. The same relations hold good of currents passing in wires.

118. A telegraphic message is transmitted between London and Edinburgh, and you are required to ascertain whether the current is directed from the former place to the latter, or *vice versa*. How would you do it? Describe, if you can, two methods of solving the problem. (1860).

(1) Insert in the circuit a galvanometer, the meaning of the deflection of which is known, say a right hand deflection is caused when the current from London enters at one of the binding-screws. Connect that terminal to "line," and the other to earth. If the needle turns to the right the current comes from the London station.

(2) Pass the current through a solution of sulphate of copper by two wires dipping into it; the one which shows the formation of bright copper is that to which the current is directed.

119. Describe the construction of a relay; and show how, by means of it, a local battery may be put in action by a person operating at a distance. (1867).

A relay consists of an electro-magnet, one end of the wire of which receives the line current, the other end being connected with the earth. The armature of this electro-magnet works on a pivot, so that when one end is attracted by the electro-

magnet, the other touches a pin in connection with a local battery. This local battery is used to work the Indicator, the armature of which follows the movements of that of the relay.

120. In the absence of iron or any other body possessing distinct magnetic properties, how would you construct an instrument which might point to the magnetic north? (1862).

If a current is sent through a solenoid, suspended on an Ampère's stand, it will point north and south. It has been found that a sinuous current destroys the effect of a straight current of the same length as its axis; the effect of the straight portion of the current in a solenoid is therefore neutralised. Each coil will place itself at right angles to the magnetic meridian, the whole solenoid will therefore place itself so that its axis is parallel to the magnetic meridian, and its north pole will be that in which the current circulates in a direction contrary to that of the hands of a watch.

121. Describe a simple magneto-electric machine, and state the general principles on which its action depends. (1864, 1875).

A powerful battery of permanent horse-shoe magnets is fixed in a frame in such a manner that an electro-magnet may be made to revolve with its poles in close proximity to those of the permanent magnet. The presence of the steel magnet induces a temporary current in the wire

composing the coils of the electro-magnet, causing in the latter a momentary magnetism. As the poles of the respective magnets separate, this temporary magnetism will disappear, to be renewed, but in the contrary direction, when, in the course of their revolution, the poles again approach each other. The soft iron cores of the electro-magnet when thus magnetized, induce currents in the wire surrounding them in the same way as a current is induced in a helix by inserting a magnet. The ends of the wires of the electro-magnet are connected with a commutator, which has the effect of utilising the currents in one direction only, if desired.

122. Will the handle of a magneto-electric machine be more difficult to turn when the current is complete or when it is broken? Give a reason for your reply. (1875).

It will be more difficult to turn the handle when the current is complete. As the poles of the electro-magnet pass those of the permanent magnet, currents are set up in opposite directions, attractions ensue and difficulty will be experienced in actuating the machine.

123. An electrical current may pass from A to B by either of two wires ACB, ADB, the resistances of which are 3 and 7 respectively. What will be the resistance of a single wire which replaces ACB, ADB in such a way as not to produce *any alteration* in the current in the rest of the *circuit?* (1875).

Let r_1 and r_2 be the resistances of the wires ACB, ADB, and R the required resistance of the single wire,

then $\frac{1}{R} = \frac{1}{r_1} + \frac{1}{r_2}$, $\therefore R = \frac{r_1 r_2}{r_1 + r_2} = \frac{3 \times 7}{3 + 7} = \frac{21}{10} = 2{\cdot}1$

124. State the law of the division of an electric current in two branches of a circuit, when part of the current is shunted. (1879).

(1) The sum of the strengths in the divided parts of a circuit equals the strength of the principal current, and (2) the strengths of the currents in the divided parts of a circuit are inversely as their resistances.

125. A tangent galvanometer of 4 Ohms resistance forms part of a circuit whose total resistance is 80 Ohms. The galvanometer is then shunted by a wire whose resistance is 4 Ohms. Find the ratio of the currents in the galvanometer before and after it is shunted. (1879).

Let R = the resistance of the galvanometer, and S that of the shunt, then the resistance of the shunted galvanometer $= \frac{R\,S}{R + S}$,

$$\begin{aligned} \therefore \text{Ratio required} &= R : \frac{R\,S}{R + S} \\ &= 1 : \frac{S}{R + S} \\ &= R + S : S \\ &= 4 + 4 : 4 \\ &= 8 : 4 \\ &= 2 : 1 \end{aligned}$$

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E. THERMO-ELECTRICITY.

126. Describe the construction and explain the principles and application of the thermo-electric pile. (1860, 1862, 1872, 1873).

A thermo-electric pile consists of a series of bars of two dissimilar metals, generally bismuth and antimony when the heat to be applied is not very great, soldered together at alternate ends. A number of these couples are insulated from one another and placed in a frame in such a manner that the soldered ends are exposed. Binding screws are attached to the first antimony and last bismuth bar respectively.

If heat is applied to the soldered junctions, and wires led from the binding screws to a galvanometer of low resistance, it will be found that a current is set up, proceeding from the bismuth to the antimony; if cold is applied to the same ends, the current will go in the contrary direction. The source of energy, therefore, is heat, which is converted into electricity.

127. State and explain the effect produced when a strong electric current is passed for some time through a thermo-electric pile and the pile is immediately afterwards connected with a galvanometer. (1872).

The junctions through which the current passes *will be heated*, and the galvanometer, when sub-

stituted for the battery, will show the presence of a current in the opposite direction, until equality of temperature is restored. This is called the *Peltier* effect.

128. There are two thermo-electric piles, one connected with a galvanometer containing a great length of wire and the other with one containing only a small length: find in which of these piles it would be most beneficial to increase the number of pairs. (1862).

Since it is most advantageous that the external resistance should be the same as the internal, the larger resistance of the long coil galvanometer should be met by increasing the number of pairs.

129. Describe the Thermo-pile and Reflecting galvanometer, explaining the various adjustments which combine to render the arrangement very delicate for the measurement of radiant heat. (1873).

The thermo-pile is mounted on a stand capable of being raised and placed at any angle, so that the rays of radiant heat may fall perpendicularly on the face of the pile. A polished silver cone is frequently fitted on the end of the pile. Between the pile and the radiating substances screens of various shapes and sizes are placed, and the terminals are connected with those of a galvanometer, whose resistance is duly proportioned to that of the pile.

(For a description of the Thermo-pile see No. 126, and for that of the Reflecting Galvanometer, see *No. 112*).

MISCELLANEOUS QUESTIONS FOR PRACTICE.

1. How would you proceed to make a magnet (1) by single touch, (2) by double touch?

2. Draw diagrams showing the curves assumed by iron filings when sprinkled over (1) a bar magnet laid lengthwise, (2) two magnets placed vertically, (3) a bar magnet with consequent poles. What do we learn from these curves?

3. How would you make a magnet with consequent poles by means of a regularly magnetized bar?

4. In making a magnet to show the dip, should the bar be magnetized before or after it is centred?

5. How is it that a magnet will support several pieces of iron end to end?

6. Define coercive and portative force. What is Häcker's formula?

7. Give a concise explanation of the methods employed in observing and recording the variations of the declination needle.

8. How would you make an astatic system without the aid of magnetized needles?

9. How would you counteract the influence of surrounding iron on a ship's compass?

10. In what respect does a Jamin's magnet *differ from an* ordinary one?

11. What effect has temperature on a magnet?

12. Describe Grove's experiment to illustrate the probable cause of the lengthening of a magnetized bar.

13. What is the "set" of a perfectly astatic system?

14. At a certain place a needle makes 71 oscillations in the same time as at another place it makes 100: compare the magnetic intensities at the two places of observation.

15. A needle under the influence of the earth's magnetism alone makes 20 oscillations in 100 half seconds, while, under the combined influence of the earth's magnetism and of the pole of a certain magnet, it performs 20 oscillations in 50 half seconds: compare the force exerted on the needle by the pole of the magnet with that exerted by the earth.

16. If the needle is similarly deflected by the pole of a second magnet held at the same distance as the first, and it is found to make 20 oscillations in 30 half seconds, what will be the intensity of this pole's magnetism, compared with that of the first?

17. The horizontal intensity of the earth's magnetic force is 3·89, taking as units the foot, grain and second. What is its value according to the C. G. S. system? (One inch = 2·54 centimetres; one grain = 0·064799 gramme).

18. What is the relation between electrical and *thermal conductivity*?

19. In what different ways may electricity be developed?

20. A crystal of tourmaline is electrically affected by the presence of a heated body; how would you arrange an experiment to show this?

21. What is the principle of Bohnenberger's gold leaf electroscope? By what modern instrument has the use of this been to a great extent replaced?

22. When using an electrical machine it is necessary to suspend a chain from it; why? What important experiment bearing upon this did Faraday make?

23. Explain the action of the ring in Winter's machine.

24. Describe and explain the principles and action of the following machines: the Holtz, the Bertsch, the Carré, the Hydro-electric.

25. A chain is suspended from the rubber of a plate machine and the hand is placed on the prime conductor; what happens when the handle is turned?

26. How would you arrange a battery of 4 similar Leyden jars in order to charge them by cascade? If the first jar receives on the inside a charge $= 1$, causing on the outside a charge $= 0{\cdot}9$, what will be the quantity of positive electricity developed?

27. If the energy of the spark obtainable in the *ordinary* way from one of the above jars $= 1$, what

will be its energy when they are arranged in cascade?

28. Show that the whole charge in a battery of similar jars charged by cascade, only equals the charge of a single jar.

29. An artificial head of hair is attached to the prime conductor of a machine in action: the individual hairs separate; state and explain what happens when the hand is placed near the hair.

30. State and explain what happens when a Leyden jar is discharged in the midst of gunpowder, (1) a piece of moist string being placed in the circuit, (2) the circuit being entirely metallic.

31. The charge from a Leyden jar is sent through a wire of a certain diameter, and an exactly equal charge is sent through another wire, five times the diameter of the former; what will be the amount of heat produced, taking that in the smaller wire as unity?

32. What experiments can be performed in support of the contact theory?

33. Describe and explain the action of the following forms of cell: Bunsen, Smee, Single fluid bichromate, chloride of silver, Leclanché, Planté's secondary.

34. Which form of cell is best suited for (1) induction coils, (2) electro-magnets, (3) electro-deposition?

35. On what does the internal resistance of a battery depend?

36. How should we be guided in the choice of a galvanometer?

37. Explain the principle and method of using the sine galvanometer.

38. The current from a battery, when sent through a tangent galvanometer, produces a deflection of 20°, while that from another battery causes a deflection of 26°30′. Compare the strengths of the two currents.

39. There are eight similar cells: in what different ways may they be connected? If the internal resistance of each cell = 4 and the external = 10, find the strength of the current in each of the different arrangements.

40. Given a battery, a set of resistances, a Wheatstone's bridge and a galvanometer: how can the resistance of the galvanometer be determined?

41. How can Ohm's law be proved experimentally?

42. A current is sent from a battery of 10 cells through (1) a voltameter containing acidulated water, (2) another containing chloride of lead, (3) another containing a saturated solution of nitrate of silver. How much hydrogen will be evolved, and how much lead and silver deposited when 13 grammes of zinc are being dissolved in each cell?

43. What are the chief objections to the use of the voltameter as a measurer of current strength?

44. A voltameter and a tangent galvanometer

are included in the same circuit, and it is found that with a certain battery 60 cubic centimetres of hydrogen are evolved per minute, while the galvanometer needle is deflected 45°; how many cubic centimetres would be disengaged if the deflection of the same needle were 30°?

45. What is meant by the passive state of iron?

46. A spiral of copper wire is suspended vertically, the upper end is connected rigidly to a binding screw, the lower end touches the surface of mercury; state and explain what happens when a current is sent through the spiral.

47. A galvanometer, a copper wire and two similar metal plates separated by water are included in a circuit with a couple of Daniell's cells. The deflection of the galvanometer needle during the first few minutes is found to decrease rapidly. The cells are removed and the circuit closed; the needle is again deflected, but in the opposite direction, and gradually returns to zero. Ascribe these effects to their proper causes.

48. How would you arrange an experiment to show that different parts of the same current repel each other?

49. What effect will be produced by sending a current through a rectangular conductor which is capable of moving freely about an axis passing through the middle of its longer side and through its centre of gravity?

50. In making an electro-magnet how should

we be governed in the choice of size and leng of wire?

51. What will be the effect of interposing copper cylinder between the soft iron of an ele tro-magnet and the wire?

52. Describe the action of the syphon recorde

53. How is the position of a fault in a cab determined?

54. By what arrangement can a current be se simultaneously in both directions through the san wire?

55. How would you charge a Leyden jar l means of an induction coil?

56. A powerful magnet is brought near a vacuu tube through which a coil is passing. What ha pens?

57. How does a paramagnetic liquid behave whe under the influence of a powerful electro-magnet

58. Which of the following, arranged in couple would form the most powerful thermo-pile? whi combination would give the least electromoti force?—lead, zinc; copper, iron; platinum, zin antimony, bismuth; nickel, iron.

59. How would you determine the electro-moti force of a thermo-electric pile?

60. What is the theory of the Gramme machin

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